Multimodal Neuromonitoring since 2000

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- **Research grants**
  - Swiss National Science Foundation
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  - Nestle Health Science Research

- **Speaker and consultant fees**
  - Nestle Health Science Research
  - Integra Neurosciences
  - Bard Medical
Acute Brain Injury

- Neuroworsening
- Intracranial volumes
- Cerebral perfusion
- Systemic injury
- Energy substrates
- Seizures
Neuroworsening

- Clinical evaluation
- Neuroimaging
Consensus summary statement
of the International Multidisciplinary
Consensus Conference on Multimodality
Monitoring in Neurocritical Care

A statement for healthcare professionals from the
Neurocritical Care Society and the European Society
of Intensive Care Medicine

Summary of recommendations from the individual
consensus conference topics

Clinical evaluation

We recommend against performing sedation interruption or wake-up tests among brain-injured patients with intracranial hypertension, unless benefit outweighs the risk. (Strong recommendation, low quality of evidence.)
ICP can be elevated despite absent mass lesions on CT-scan

O’Sullivan J Neurosurgery 1994

25 y, day 2 post-TBI

ICP > 25 mmHg

normal control
Intracranial volumes

- ICP thresholds
- Brain elastance (P/V curve)
- Autoregulation
“Historical” ICP thresholds

- **>15 mmHg**
    - 100 pts, retrospective

- **>20 mmHg**
    - 207 pts, retrospective

- **> 20 mmHg**
  - Eisenberg HM et al. *J Neurosurgery* 1988
    - 70 pts, prospective

- **15-25 mmHg**
  - Saul TG et al. *J Neurosurgery* 1982
    - 233 pts, retrospective
Decompressive Craniectomy in Diffuse Traumatic Brain Injury

ICP > 20 mmHg for > 15 min

% unfavorable outcome

"one size fits all approach"
PRx (pressure reactivity index) = on-line correlation coefficient between ICP and MAP
Patient-specific individualized ICP thresholds

PRx >0.2 = impaired autoregulation

“individualized approach”
Cerebral perfusion

- "CBF surrogate"
- Secondary ischemia
- "Optimal" individual CPP
Monitoring of Brain and Systemic Oxygenation in Neurocritical Care Patients

Mauro Oddo · Julian Bösel · and the Participants in the International Multidisciplinary Consensus Conference on Multimodality Monitoring

\[ \text{PbtO}_2 \approx \text{CBF} \times (\text{PaO}_2 - \text{PvO}_2) \]

\( \text{PbtO}_2 \)
Normal 25-40 mmHg
Low <15-20 mmHg
N=103 patients with severe TBI monitored with ICP and PbtO₂

TABLE 5. Outcome in Patients With Intracranial Hypertension (Intracranial Pressure > 20 mm Hg) and Low Cerebral Perfusion Pressure (< 60 mm Hg) According to the Presence or Absence of Brain Hypoxia (PbtO₂ < 15 mm Hg)\(^a\)

<table>
<thead>
<tr>
<th>Patients With Favorable Outcome, n (%)</th>
<th>Intracranial Hypertension (n = 74)</th>
<th>Low CPP (n = 75)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brain hypoxia</td>
<td>20/43 (46)</td>
<td>18/46 (39)</td>
</tr>
<tr>
<td>No brain hypoxia</td>
<td>25/31 (81)</td>
<td>24/29 (83)</td>
</tr>
<tr>
<td>(p)</td>
<td>&lt; .01</td>
<td>&lt; .01</td>
</tr>
</tbody>
</table>
Accuracy of Brain Multimodal Monitoring to Detect Cerebral Hypoperfusion After Traumatic Brain Injury*

Pierre Bouzat, MD, PhD¹,²; Pedro Marques-Vidal, MD, MPH³; Jean-Baptiste Zerlauth, MD⁴; Nathalie Sala, MD¹; Tamarah Suys, RN, MPH¹; Patrick Schoettker, MD⁵; Jocelyne Bloch, MD⁶; Roy T. Daniel, MD⁶; Marc Levivier, MD⁶; Reto Meuli, MD⁴; Mauro Oddo, MD¹
ICP + PbtO₂ (and CMD) is better than ICP alone to detect cerebral hypoperfusion after severe TBI.
« Optimal » individualized MAP/CPP

$PbtO_2$ response to MAP/CPP augmentation after SAH

- **H**: induced hypertension alone
- **HH**: hypervolemia-hemodilution
- **HHH**: H + HH

Systemic injury

- Oxygen
- Hemoglobin
- Glucose
Anemia and brain oxygen after severe traumatic brain injury

Mauro Oddo
Joshua M. Levine
Monisha Kumar
Katia Iglesias
Suzanne Frangos
Eileen Maloney-Wilensky
Peter D. Le Roux

![Graph showing relationship between hemoglobin level and PbtO2 (mmHg).](image)

- Hemoglobin level (g/dl)
  - [≤9]: N=157, p<0.001
  - [9.1–10]: N=87, p=0.748
  - [10.1–11]: N=94, p=0.541
  - [>11]: N=136

Mean ± 95% CI
Anemia and brain oxygen after severe traumatic brain injury

Table 3 Relationship between anemia with simultaneous compromised PbtO$_2$ and unfavorable outcome

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds ratio</th>
<th>95% CI</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemia (Hgb ≤ 9 g/dl) and simultaneous brain hypoxia (PbtO$_2$ &lt; 20 mmHg)</td>
<td>6.24</td>
<td>1.61; 24.22</td>
<td>0.008</td>
</tr>
<tr>
<td>Admission GCS</td>
<td>0.80</td>
<td>0.65; 1.00</td>
<td>0.045</td>
</tr>
<tr>
<td>Marshall CT grade</td>
<td>1.69</td>
<td>0.98; 2.93</td>
<td>0.059</td>
</tr>
<tr>
<td>APACHE II score</td>
<td>1.27</td>
<td>1.02; 1.58</td>
<td>0.030</td>
</tr>
<tr>
<td>Age</td>
<td>1.01</td>
<td>0.97; 1.04</td>
<td>0.758</td>
</tr>
</tbody>
</table>
Cerebral microdialysis

Microdialysate collected via outlet tube
Isotonic fluid perfused via inlet tube

Microdialysis catheter
Brain interstitium
Dialysis membrane
Molecules in ECF equilibrate across dialysis membrane

Normal human brain (perfusion rate 0.3 μl/min)

Glucose 1.7 ± 0.9 mmol/L
Lactate 2.9 ± 0.9 mmol/L
Pyruvate 166 ± 47 μmol/l
La/py ratio 23 ± 4
Glutamate 16 ± 16 μmol/l
## Consensus statement from the 2014 International Microdialysis Forum

**Table 2** Summary of the evidence for how brain chemistry relates to different aspects of the management of patients with TBI and SAH

<table>
<thead>
<tr>
<th>How microdialysis monitoring can be used in neurocritical care</th>
<th>Traumatic brain injury</th>
<th>Subarachnoid hemorrhage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outcome and prognostication</td>
<td>[51, 53, 78]</td>
<td>[67, 79, 81]</td>
</tr>
<tr>
<td>Early warning system of secondary insults</td>
<td>[26, 27]</td>
<td>[28, 29, 80, 82]</td>
</tr>
<tr>
<td>Monitoring and treatment of low cerebral glucose; guiding systemic glucose management and insulin use</td>
<td>[56, 61, 62, 64, 65]</td>
<td>[56, 63, 83, 84]</td>
</tr>
<tr>
<td>Monitoring during CPP-augmentation/reduction</td>
<td>[48, 85, 86]</td>
<td>[54, 87]</td>
</tr>
<tr>
<td>Monitoring during neurological wake-up test (tolerating moderate rises in ICP)</td>
<td>[25, 88]</td>
<td></td>
</tr>
<tr>
<td>Deciding on transfusion thresholds</td>
<td></td>
<td>[89]</td>
</tr>
<tr>
<td>Evaluating the effect of body temperature on cerebral chemistry</td>
<td>[90]</td>
<td>[91]</td>
</tr>
<tr>
<td>Monitoring after decompressive craniectomy</td>
<td>[92]</td>
<td>[93]</td>
</tr>
</tbody>
</table>
Evidence from clinical studies using cerebral microdialysis

- **Intensive vs. Moderate glycemic control after ABI**

  - Higher rates of low cerebral extracellular glucose and increased cerebral metabolic distress

  - Helbok R et al. *Neurocritical Care* 2010
  - Kurtz P et al. Neurocrit Care 2013
NICU patients
blood* AND brain** glucose control

Blood glucose (mmol/L)

- **< 4**
- **4-6**
- **6-7.5**
- **7.5-10**
- **> 10**

- Risk of neuroglucopenia
  - Neuroglucopenia
  - Energy crisis
  - Cell injury

- Safe
- Cell injury & death

* systemic arterial/venous
** cerebral microdialysis
Energy substrates

- Glucose
- Lactate
- Ketones
Cerebral Metabolism in Brain-Injured Patients

- Increased non-ischemic lactate release
- Increased lactate uptake
- Increased cerebral glucose utilization
- Reduced availability of brain glucose

GLUCOSE

LACTATE

Vespa P et al. *JCBFM* 2005
Helbok R *Neurocritical Care* 2010
Timofeev I et al. *Brain* 2011

Glenn T *JCBFM* 2003
Gallagher C *Brain* 2009
Oddo M *Stroke* 2012
Sala N et al. *JCBFM* 2013
Jalloh I et al. *J Neurotrauma* 2013
Bouzat P et al. *Int Care Med* 2014
Bouzat P; Oddo M. *Curr Opin Crit Care* 2014
Glenn T *J Neurotrauma* 2014
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Table 1 Reasons why we monitor patients with neurologic disorders who require critical care

- Detect early neurological worsening before irreversible brain damage occurs
- **Individualize patient care decisions**
- Guide patient management
- Monitor the physiologic response to treatment and to avoid any adverse effects
- Allow clinicians to better understand the pathophysiology of complex disorders
- Design and implement management protocols
- Improve neurological outcome and quality of life in survivors of severe brain injuries
- Through understanding disease pathophysiology begin to develop new mechanistically oriented therapies where treatments currently are lacking or are empiric in nature
A trial of treatment of intracranial hypertension with vs. without ICP monitoring
• ICP vs. no-ICP monitoring in the treatment of intracranial hypertension following TBI**
  – 50% reduction of the number of treatments administered per patient
  – Reduction of the number of ICU days during which patients received brain-specific treatments (e.g., administration of hyperosmolar fluids and the use of hyperventilation)

✓ ICP monitoring was better than no ICP monitoring in guiding therapy of intracranial hypertension

** only 30% of patients had elevated ICP
• Individualized neurocritical care

XX century
- ICP/CPP therapy
- “one size fits all” management

XXI century
- MMM guided therapy
- “individualized” management
Brain multimodal monitoring – how it changed patient care over the last decade

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Condition</th>
<th>Management</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICP + PbtO₂</td>
<td>TBI</td>
<td>Tolerate ICP 25 mmHg if PbtO₂ &gt;20 mmHg; aggressive ICP therapy if high ICP/low PbtO₂</td>
</tr>
<tr>
<td>PbtO₂, CMD</td>
<td>TBI/SAH</td>
<td>Management of cerebral ischemia; target MAP/CPP individually</td>
</tr>
<tr>
<td>PbtO₂</td>
<td>SAH</td>
<td>Triple H ➔ induced hypertension</td>
</tr>
<tr>
<td>PbtO₂, CMD</td>
<td>TBI/SAH</td>
<td>Management of RBC transfusion</td>
</tr>
<tr>
<td>PbtO₂</td>
<td>TBI/SAH</td>
<td>Hypoxia ➔ controlled oxygenation, moderate hyperventilation, protective ventilation</td>
</tr>
<tr>
<td>CMD</td>
<td>TBI/SAH</td>
<td>“Moderate” glycemic control; “Optimal” fluid and osmotic therapies</td>
</tr>
</tbody>
</table>
Acute Brain Injury

- Neuroworsening
- Intracranial volumes
- Cerebral perfusion
- Systemic injury
- Energy substrates
- Seizures

Monitoring modalities

- EEG
- Pupillometry
- ICP
- PRX
- PbtO₂
- TCD
- qEEG
- NIRS
- PbtO₂
- CMD
- CMD
- EEG